A Model of Time-Critical Decision Making

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It is difficult to compute optimal actions for time-critical decision problems, yet real-world agents must act within the time constraints of their domain. In time-pressured domains, the optimal decision may be to act immediately or to gather more information before acting.

For example, a doctor who is caring for a patient who presents with sudden, sharp chest pain might conclude that the patient probably has a life-threatening pneumothorax. In the absence of any action, the patient would be at high risk for changing to other less desirable states, such as "cardiac arrest." If the diagnosis were certain, the optimal action would be to drain the pneumothorax immediately, by placing a needle or a catheter in the chest. When the diagnosis is uncertain —as is usually the case—the optimal initial action depends in a complex way on the dynamics of the system, the degree of uncertainty in the patient state, and on the relative risks of tests and treatments. A test that gives perfect information after a lengthy delay—for example, a chest X-ray that takes 20 minutes—cannot be the preferred action. A test that gives partial information after a short delay—for example, an inference procedure that gives an answer after one minute—may be the optimal initial action.

Methods. Traditional decision-analytic methods are not well suited to describe the trade-off of the benefit of diagnostic tests and the cost of test-induced treatment delays for critical patients. We have developed a methodology to represent and reason about the characteristics of optimal time-critical decision making in emergency medicine; the dynamic decision network (DDN) enables a decision-theoretic planner to choose among alternative actions and test/action strategies. The DDN models the patient as a discrete stochastic dynamic system; it combines a Bayesian diagnostic network and a Markov model of patient dynamics.

The DDN for pneumothorax (PTX-DDN) is the first step in the development of a DDN that represents the decision problem of the initial management of patients who present to the emergency department complaining of chest pain. PTX-DDN combines a Bayesian belief network that assesses the probability of pneumothorax, a dynamic model of the progression over time of patients with pneumothorax (with and without treatment), and a value model for the possible outcome states (see Figure). For specific presenting symptoms and findings, the solution of the PTX-DDN describes the optimal test and treatment sequences for patients who may have a pneumothorax.

PTX-DDN includes nodes for 8 historical findings, 5 symptoms, 15 signs, 3 diagnostic tests, and 3 treatment interventions. The probabilistic relationships in PTX-DDN were derived by combining expert opinion with the relationships in the INTERNIST database.

Results. The solutions for PTX-DDN under varying presenting symptoms show that variations in the certainty of the diagnosis lead to variations in the cost of the treatment delay, which changes the optimal treatment strategy. For example, solutions of PTX-DDN define the degree of certainty in the diagnosis of tension pneumothorax that must be present before immediate treatment with a chest tube is preferred over diagnostic testing with a chest radiograph.

Conclusions. The prototype PTX-DDN demonstrates a method to compare the benefit of a diagnostic test and the cost of the associated delay in treatment. Dynamic decision networks appear to be a powerful modeling methodology for representing and reasoning about time-critical decision making in emergency medicine.

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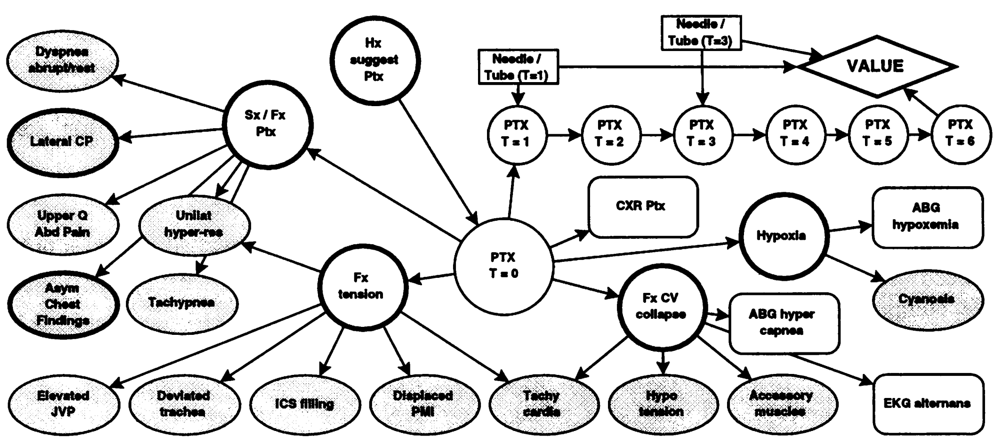

Figure. A portion of PTX-DDN. Nodes with heavy outlines represent abstractions or summaries of multiple observations; shaded ovals represent symptoms or signs; rounded rectangles represent laboratory-test results; rectangles are therapy decisions, and the diamond is the value node.

Abbreviations: PTX: pneumothorax; Hx: history; Sx: symptom; Fx: finding; CP chest pain; CV: cardiovascular; ABG: arterial blood gas; JVP: jugular venous pressure; ICS: intercostal space; CXR: chest Xray.